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TEMPERATURE DEPENDENCE OF THE DIELECTRIC CONSTANT OF QUARTZ POL--ETC(U)

MAY 78 F C ESSIG, J W BATTLES

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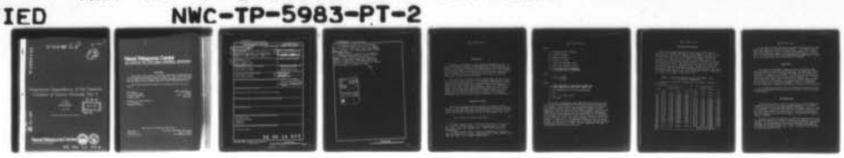

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Part 2

Temperature Dependence of the Dielectric Constant of Quartz Polymide. Part 2

by
F. C. Essig
J. W. Battles
Research Department

MAY 1978

Approved for public release; distribution unlimited.

Naval Weapons Center
CHINA LAKE, CALIFORNIA 93555

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FOREWORD

This report is the result of a radome measurement program performed for the Weapons Development Department, Code 39. This is a final report and represents work performed during February and March 1978. The funding was supplied under AIRTASK Project No. A03P-03P2/008C/7W055/-001.

This report has been reviewed for technical accuracy by Mr. D. J. White.

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(U) *Temperature Dependence of the Dielectric Constant of Quartz Polymide. Part 2*, by F. C. Essig and J. W. Battles. China Lake, Calif., Naval Weapons Center, May 1978. 4 pp. (NWC TP 5983, Part 2, publication UNCLASSIFIED.)

(U) The dielectric constant and loss tangent of quartz polymide were measured as a function of temperature, in the presence of flowing air, up to 1000°F. No significant changes were observed as a function of temperature. The average value of the effective dielectric constant was found to be 3.05 and the loss tangent to be 0.0021 at 35 GHz.

INTRODUCTION

Preliminary measurements of the temperature dependence of the dielectric constant of quartz polymide were made in 1977 by Battles and Kuehn.[1] The results showed that the polymide was a very stable material. No substantive changes in either dielectric constant, K_e, or loss tangent, $\tan\delta$, were observed over the temperature range from room temperature to 840°F. However, there was a scattering of $\tan\delta$ values--a difficult measurement to make with high precision.

One limitation of the first series of measurements was that there was little or no oxygen present in the waveguide containing the polymide sample during the heating cycle. A cooling gas of 98% N_2 and 2% H_z was deliberately vented through the waveguide to prevent the formation of oxides on the walls of the copper waveguide. Thus, there was no way to judge whether oxygen would cause enhanced degradation of the polymide sample. It was considered desirable to conduct a second series of measurements in which the sample could be heated in the presence of flowing air and its dielectric properties measured at room temperature.[2]

EXPERIMENTAL METHOD

The circular waveguide doppler generator technique described in reference 2 was again employed. This measurement technique was followed exactly and the equations stated therein were used to calculate the real part of the dielectric constant, K_e, and the loss tangent, $\tan\delta$, where

$$K_e = [(f_c/f_\tau)^2 + (f_d/f_\tau)^2(c/4\pi r f_o)^2]A \quad , \tag{1}$$

[1](U) Naval Weapons Center. *Temperature Dependence of the Dielectric Constant of Quartz Polymide*, by J. W. Battles and K. D. Kuehn. China Lake, Calif., NWC, December 1977. (NWC TP 5983, publication UNCLASSIFIED.)

[2](U) Naval Weapons Center. Dielectric Measurements on Oxidized Quartz Polymide, by K. D. Kuehn. China Lake, Calif., NWC, February 1978. (Reg. Memo 39042-15-78, document UNCLASSIFIED.)

where

f_c = waveguide cutoff frequency

f_τ = carrier frequency

f_d = doppler frequency

c = velocity of light

r = radius of waveguide circle

f_o = rotational frequency of post

$$A = \frac{\text{x sectional area of waveguide}}{\text{x sectional area of dielectric}}$$

and

$$\tan\delta = \frac{-\ln R}{2\omega\ell\sqrt{\varepsilon'\mu_o}} ,$$

where

$$R = \frac{\text{signal amplitude at input end of sample (A)}}{\text{signal amplitude at exit end of sample (B)}}$$

ℓ = arc length from (A) to (B) through sample

$\omega = 2\pi f_\tau$

$\varepsilon' = K_e\varepsilon_o$, $\varepsilon_o = 8.854 \times 10^{-12}$

$\mu_o = 4\pi \times 10^{-7}$.

Two series of measurements were taken with the dielectric properties of the polymide measured at 50°F intervals from room temperature up to 1000°F. In the first series, the polymide sample was heated in a 1-inch-diameter quartz tube for approximately 2 minutes at a given temperature, with air flowing over the sample, removed, cooled to room temperature, then inserted in the circular waveguide for measurement. In the second series, measurements were again taken at 50°F intervals, but the sample was heated for 5 minutes in the presence of flowing air, in an open furnace cavity. This was an attempt to achieve better uniformity, or constancy, of the temperature during the course of sample heating. At the end of the second series, an attempt was made to obtain an additional data point at 1100°F. At this temperature the sample disintegrated and no data were obtained.

DESCRIPTION OF RESULTS

The pertinent data obtained for the two series of dielectric properties as a function of temperature are summarized in Table 1. It can be observed that, on the average, the data agree reasonably well for both series and there are no significant changes in dielectric properties as a function of temperature. The average value of the effective dielectric constant, K_e, was found to be 3.05 and the average loss tangent was 0.0021. The variation in the calculated values of K_e is quite small, with the maximum deviation in either run being 2.9%. The data for tanδ showed considerably more variability but still no discernible trend as a function of temperature was observed. The difficulty in the measurement of tanδ derives from the "eyeball" estimates of the slopes of the doppler signal decay trace.

TABLE 1. Dielectric Constant, K_e, and Loss Tangent, tanδ, as a Function of Temperature.

Furnace soak times were 2 minutes on first series, 5 minutes on second series.

T, °F	First series				Second series			
	f_{RF}	$\bar{f}_d$	tanδ	$\bar{K}_e$	f_{RF}	$\bar{f}_d$	tanδ	$\bar{K}_e$
R.T.	35.14	4.492	0.0029	3.092	35.23	4.497	0.0025	3.147
200	35.23	4.500	0.0032	3.098	...	...	...	...
250	35.14	4.461	0.0027	3.052	35.23	4.455	0.0027	3.098
300	35.15	4.496	0.0028	3.096	35.23	4.433	0.0015	3.073
350	35.14	4.457	0.0020	3.047	35.22	4.443	0.0022	3.086
400	35.14	4.434	0.0017	3.024	35.22	4.466	0.0034	3.113
450	35.14	4.397	0.0027	2.990	35.23	4.435	0.0020	3.075
500	35.14	4.403	0.0020	2.982	35.20	4.429	0.0017	3.073
550	35.14	4.478	0.0013	3.068	35.18	4.429	0.0015	3.077
600	35.14	4.500	0.0035	3.102	35.06	4.384	0.003	3.046
650	35.14	4.439	0.0019	3.030	35.06	4.387	0.0011	3.049
700	35.14	4.465	0.0026	3.053	35.06	4.381	0.0011	3.042
750	35.14	4.436	0.0019	3.025	35.71	4.498	0.0010	3.064
800	35.14	4.468	0.0021	3.056	35.70	4.515	0.0020	3.085
850	35.14	4.438	0.0015	3.029	35.72	4.496	0.0020	3.060
900	35.14	4.445	0.0025	3.035	35.06	4.372	0.0015	3.032
950	...	...	...	...	35.05	4.379	0.0026	3.042
1000	35.14	4.499	0.0033	3.098	35.09	4.324	0.0020	2.972
1100	...	...	...	...	Sample disintegrated			

It was observed that there may be a moisture absorption effect that manifests itself as an increase in loss tangent. Loss tangent measurements taken immediately after the heating cycle appeared to be consistently lower than those taken on the same undisturbed sample the following day. This warrants further investigation and confirmation of signal decay curves upon which the calculation of tanδ depends.

CONCLUSIONS

This series of measurements confirms earlier observations that quartz polymide is a thermally stable material. No significant change in either the dielectric constant or loss tangent of the material was observed up to temperatures of 1000°F. In this series the polymide was exposed to a continuous flow of air during the heating cycle. At elevated temperatures (above 850°F) a white, dusty deposit began to appear on the surface of the polymide. This appears to be the beginning of the disintegration of the binding compound. However, its appearance caused no measurable changes in the dielectric properties of the material.

It is tentatively concluded that the absorption of moisture on raw or unprotected radome surfaces may cause an increase in the loss tangent of the material.

RECOMMENDATIONS

Although there seems to be little reason to be concerned about the temperature stability of the quartz polymide material--up to 1000°F--it is suggested that two more experiments be performed. First, it would be interesting to learn more about the effect of absorbed moisture upon the dielectric properties of the material. A series of measurements made with humidity as a controlled variable, at representative temperatures, is proposed.

Secondly, it would be desirable to refine the measurement technique for the loss tangent in an effort to reduce the error bar on the results obtained. It is proposed to devise an electronic amplitude comparison technique that would eliminate the necessity of manual estimation of the slope of the signal decay curve. This is the source of the spread in calculated values of tanδ.